From flood flows to flood maps: the understanding of flood probabilities in the United States

Rumsey, Brian

From Flood Flows to Flood Maps: The Understanding of Flood Probabilities in the United States

Brian Rumsey[*]

Abstract: *»Von Flutströmen zu Flutkarten: Das Verständnis von Flutwahrscheinlichkeiten in den Vereinigten Staaten«*. In the twentieth century, probability became an important tool in the understanding of flood recurrences and magnitudes. This article focuses on the development of probabilistic flood understandings in the United States. Early efforts focused on projecting flood volumes, but maps of flood risk, brought about in large part by the National Flood Insurance Program, did much to cultivate this way of thinking in a broad audience. Engineers such as Weston Fuller and Allen Hazen, and geographer Gilbert White, play important roles in the trajectory developed in the article. The closely related ideas of the hundred-year flood and the hundred-year floodplain became standard terminology for communicating flood risk, but the knowledge behind them has been called into doubt by the realization of rapid, anthropogenic climate change.

Keywords: Environmental history, National Flood Insurance Program, Weston Fuller, Allen Hazen, quantification methods, 100-year flood.

During the building of the Melan Arch Bridge over the Kansas River in Topeka in 1897, the city engineer's records, spanning 25 years, indicated a 15-foot range between the highest and lowest recorded water levels. "[T]he oldest inhabitant, who claimed that he had seen the river go clear out of its banks and flood the entire valley prior to 1850, was deemed to be in his dotage and untrustworthy," recounted civil engineer H. V. Hinckley (Hinckley 1914, 622). A mere six years later, however, a large flood caused the city engineer's records to be amended to reflect a 28-foot range, and the bridge sat under six feet of water. "The oldest inhabitant was vindicated, and the river proved what everyone should have known," Hinckley wrote – that 25 years was hardly a sufficient sample of time to expect to see a river's greatest flood (Hinckley 1914, 622). The waters of 1903 merely put the bridge out of commission temporarily, but after enduring several other floods higher than those its builders designed for, the Melan Arch Bridge collapsed during a flooding event in July of 1965, costing the life of a commuter who became trapped in his vehicle (Hooper 2007).

[*] Brian Rumsey, Department of History, University of Kansas, Lawrence, Kansas, USA; brumsey@ku.edu.

DOI: 10.12759/hsr.40.2015.2.134-150

If the bridge was being built today, critics might ask whether its planners were taking into account the hundred-year floodplain. At the dawn of the twentieth century, however, such terminology was not yet in use. There existed no accepted method to estimate the frequency and probability of floods of particular magnitudes. In a few cases, engineers had offered formulas that could apply to individual streams, but more commonly, people simply had to rely on recorded flood levels, or even the memory of local residents. In order to more accurately understand the levels of flooding that they needed to plan for, the designers of the Melan Arch Bridge would have needed a much more lengthy chronological record – or another method of understanding flood levels. Such a method would develop over the course of the twentieth century, elucidating assumptions about the functioning of the natural world, specific socio-political imperatives, and an increased awareness of probability within the public consciousness of the United States.

The growth of the idea that river floods are a quantifiable risk is a process to which few historians have devoted much attention, yet it yields insights into the ways that people have known their natural surroundings numerically, and into the social and political as well as the mathematical and statistical elements of how and when this knowledge has been produced (Reuss 2002; Kirby and Moss 1987).[1] Today, the methods and language of probability are crucial to the operation of the National Flood Insurance Program (NFIP), an institution created by the National Flood Insurance Act of 1968, and largely because of the NFIP's needs, detailed surveys of flood risk in many parts of the United States exist. This may be seen as an attempt to account for nature not so much to enable sustainable use of natural resources, but to enable a sustainable method of coping with environmental risk.[2] Due to various factors, the NFIP has not been an especially *successful* example of taking nature into account, but its creators certainly had that intention.[3]

Civil engineers in private practice made important early contributions to humanity's ability to view this specific part of the natural world through the lens of probability. Their work was originally most important in creating cost-benefit analyses of proposed flood control structures like levees and reservoirs, analyses that saw an increase in demand as the federal government took an

[1] Martin Reuss has provided an insightful look at some of the earlier developments in flood probability studies, and the author wishes to acknowledge his debt to Reuss's work in building an understanding of the early developments in flood probability analysis.

[2] In contrast to the emphasis of Höhler and Ziegler (2010) on taking nature into account "for the sake of maximizing sustained yield and producing sustainable quality" (417).

[3] Despite repeated legislative modifications, the NFIP has struggled with financial losses throughout its existence, and remains troubled as of 2014. Theodore Steinberg (2000) highlights the ways certain industries have used their lobbying power to push for weaker flood insurance regulations. He also acknowledges the problem of repetitive losses, as does Lübken (2010).

increased role in flood prevention efforts starting in the 1930s. A generation later, as flood insurance inched closer to reality in the United States, new emphasis was placed not just on predicting flood magnitudes, but on understanding the areas they would affect and on acceptable levels of risk. Since its early years, the NFIP has placed tremendous importance on the 100-year flood, a term that demonstrates the extent to which humans now endeavor to know nature through numbers. The idea of the 100-year floodplain not only suggests an ability to predict the vagaries of the natural world, but also implies an understanding of just how far people can safely push nature's limits.

Flooding is not an entirely unknown risk, in that people generally tend to have some idea that streams and rivers may swell from time to time. What is not always understood is just how likely those streams and rivers are to surge. Of course, even today, nobody can predict flood magnitudes or frequencies with complete accuracy. Over the past century, though, the study of flood frequencies has been transformed from an obscure pursuit into a well-established discipline. Today, people speak of the hundred-year flood, and the hundred-year floodplain – but where did these terms come from? How is it that one can make sense of broad portions of the United States in these terms? This is not simply a story of the upward trajectory of hydrological knowledge. Certainly, advances in hydrological understanding are crucial to our numerical understanding of the natural world in the context of floods, but this knowledge is also borne of specific social and political imperatives.

Studies undertaken upon Pittsburgh, Pennsylvania and the Dayton, Ohio area in the 1910s were much more thorough than the consideration that had been given to the construction of Topeka's Melan Bridge, and serve as representative samples of the state of the art in flood studies at that time (Flood Commission of Pittsburgh 1912). The Flood Commission of Pittsburgh was composed of civil engineers, city officials, and business leaders, and completed a study of the city's vulnerability to flooding in 1912. In the commission's report, a section analyzing future possible floods went well beyond assuming that the greatest flood of record is the maximum flood that must be planned for. Nonetheless, the commission made no attempt to mathematically determine the likelihood of such a greater flood. Rather, it justified the claim that higher floods were likely by reviewing what could have happened if recent scenarios had unfolded differently. In the winter of 1909-1910, for instance, the city had received unprecedented snowfall. "If a rain similar to any one of the frequent heavy, warm spring rains had occurred" when the winter's snows were melting, the report suggested that "the snow on the ground at the end of February, 1910, would have melted and run off with this rain," leading to a flood greater than that of 1907 (Flood Commission of Pittsburgh 1912, 48). The Miami Conservancy District (MCD), organized in response to the heavy flooding that had hit Dayton and surrounding areas in 1913, produced a several volumes of studies on the Miami River in connection with its project to build five flood control dams in the area. The engineers of the MCD stopped short of probabilistic modeling, but used several centuries of data on European river flows to observe that "floods which occur on an average of once in a century or two," which seemed an accurate appraisal of the 1913 Dayton flood's magnitude, "have been exceeded in the course of many centuries," but rarely by much. In projecting the maximum possible flood in the Miami Valley, the MCD, headed by civil engineer Arthur Morgan, theorized that by designing for a flood 40 percent greater than that of 1913, they would achieve complete safety with room to spare, assuming climatic stability (Woodward 1920, 44-5).

Neither the Topekans, nor the Pittsburghers, nor the Miami Conservancy District had the toolbox of probability at their disposal, but this situation would soon change. Weston Fuller, a civil engineer and a partner in the New York engineering firm Hazen & Whipple, published the first comprehensive statistical approach to estimating river flood frequencies and magnitudes (Fuller 1914a). Fuller himself remains a rather obscure character – he had few other publications to his credit, and his available biographical information is decidedly sparse – but his work on flood probabilities endows him with a definite historical significance. Fuller's work did have some precedents (Rafter 1903; Horton 1913), but the critical distinction between his work and that which had come before was that earlier efforts tended to focus on individual bodies of water, whereas the Fuller article proposed a method that would be applicable for rivers and streams throughout the country.

Fuller's firm, which produced much of the most important flood frequency research of the early twentieth century, was founded in 1904 by George Whipple and Allen Hazen – the latter of whom also figures prominently in this essay – and focused especially on city sanitation and water supply systems in the early twentieth century (Kennelly 1925; Hendricks 2011). It comes as little surprise that those with an interest in sanitary engineering produced much of the early American work on flood probabilities. In a contemporary debate over whether it was better for cities to build individual sewer systems for wastes and for storm runoff, or whether combined systems that would handle both types of outflow were the better choice, many sanitary engineers – including George Whipple and Allen Hazen – favored the latter solution. Thus, the potential for downpours and floods was naturally an important component of their analysis (Tarr 2002).

Fuller's paper "Flood Flows" was presented to the American Society of Civil Engineers in October 1913, and was published the following year (Fuller 1914a). Within the article, Fuller laid out the practices employed by Hazen and Whipple at the time, methods that were advanced beyond what had been described in any contemporary source (Hazen 1930). Nearly a century after its publication, Fuller's paper remains a landmark in the study of flood frequencies, and it is likewise a sign of a significant shift in the way that people, or at least experts, understood the natural world in which they lived. Though humans had been practically aware of the concept of probability for millennia – gambling and casting lots are ancient manifestations of this awareness – it had only relatively recently emerged as a field of scientific inquiry (Porter 1986; Daston 1988). To understand the behavior of the natural world through the principle of probability is an extremely different approach than believing that it adheres to simple mechanistic rules, or that it is under the control of supernatural powers.[4]

As the Topeka incident reveals, in the early years of the twentieth century, one of the greatest challenges facing anyone who wished to understand the frequency of floods in the United States was the absence of long-term records, a challenge Fuller readily acknowledged. "If the data for all the floods that have occurred in a single river for several hundred years were available, a relation could be established showing the average frequency with which floods of any size occur," the engineer wrote (Fuller 1914a, 573). Lacking the luxury of such data, however, Fuller and his colleagues were forced to devise a different approach. With the equations proposed in Fuller's article, not only could one predict the probabilities for different levels of floods on a single stream, one could do so for almost *any* stream that had at least a relatively brief flow record available. Rather than simply tabulating flood records to highlight large floods, however, these engineers offered mathematical formulae that would enable one to calculate predicted frequencies and magnitudes, even in the absence of long-term written flood records. Fifteen years was suddenly enough of a record to produce a detailed set of predictions. Hazen, though perhaps biased due to his close professional relationship with Fuller, lavished praise on the latter's publication. His hailing of the article as "the first attempt to apply the principles of probabilities to the flood problem," despite receiving a bit of pushback from contemporaries who felt that they had prior claims to this title, generally withstands scrutiny, particularly when speaking of a generalizable model rather than one created for a specific stream (Hazen 1914, 626).

Fuller's chosen method to create his formula was to utilize data from many rivers, but over a shorter period of time. "As rivers follow the same general law, it is allowable to use the data on all the rivers in the same way as those on a single river, provided such data can be put on a common basis," he argued, in defense of this method (Fuller 1914a, 574). In other words, he worked on the assumption that all streams will demonstrate a consistent relationship between average yearly floods and infrequent, high-volume events, and because of this, ten years of data from ten rivers would be nearly as good as one hundred years from one river, and fifteen years or more of data from hundreds of rivers would be far better yet. He planned to create such a common basis through the use of the yearly average flood, which is the average of the highest level of flow

[4] For a detailed discussion of the transition in understandings of natural disasters, specifically hail, from divine retribution to nature theology to experimental science, see Oberholzner (2011).

reached each year for any particular channel. "[T]he ratio of the larger floods to the yearly average floods should be the same for all rivers for the same period of time," Fuller justified (Fuller 1914a, 574). Though the assumption that short chronological records from numerous streams can stand in for longer chronological records makes a certain sense, it nonetheless suggests a certain naiveté in regard to the natural world. Since weather patterns tend to affect large areas, neighboring streams will likely share common trends. If one region had experienced an especially wet fifteen years, chances are that nearby regions might have also experienced elevated moisture during those years. By way of example, using data from the Kansas River and ten nearby streams for 1900-1910, the sample size would have been one hundred years of river data (ten years each from ten rivers), but would have shown the 1903 flood to be a one-in-ten event if it had occurred on all ten bodies of water.

Fuller offered a pair of formulas to be used in determining probable flood magnitudes. One formula produced determinations of the predicted greatest average flow over a 24-hour period to be expected during a given time period, based on the river's catchment area and a coefficient specific to an individual stream. The other formula built on the first, allowing one to use the number derived from the first formula to calculate the maximum probable flood over the same period of time. In these formulas, the coefficient played an important role. It was the component of the equation that allowed it to be applied to a wide range of streams, rather than tying it to a particular river or creek. The coefficient needed be calculated for any specific riparian location for which one wished to compute flood probabilities. The practicality of Fuller's formula was that the coefficient could be calculated based on the average yearly flood. Though this number would be more accurate the more time is taken into consideration, relatively short periods of time nonetheless provided reasonably useful data. The 25-year records used in Topeka in 1897, while they were badly insufficient as a window of time in which to look for the upper limits of flooding potential, would have been more than enough to calculate a serviceable coefficient based on average yearly floods. In his study, Fuller set a standard of 15 years as a minimum level of information for calculating a sound coefficient (Fuller 1914b, 684).

Topeka was not the site of early flood probability work, but by considering it, one can gain a two-fold insight into how the engineers working on flood probabilities needed a specific kind of data, and how their methods had difficulties incorporating other forms of flood knowledge. Without exact measurements and records from the intervening years, it would have been difficult for an engineer using Fuller's probabilistic model to incorporate vernacular knowledge of historical events such as the pre-1850 Topeka flood into a useful data set. Further, the United States was not uninhabited prior to the arrival of Europeans, and its American Indian inhabitants might have been able to corroborate the senior citizen's memory – though their knowledge would have been equally difficult for probabilistic modelers to engage with.

The products of Fuller's equations came in the form of flood flows, a measurement of volume over time. Although the determination of probable flood flows was a notable achievement, simply understanding how much water will pass through a given waterway is not the same as understanding the extent of the area that will be affected. The two types of knowledge are indeed closely related, yet far from identical. Hazen alluded to this difference in his 1930 book *Flood Flows*: "It would be theoretically possible to draw a line down the bank of a stream above which there would be only one chance in ten that water would rise in any one year," the engineer wrote, "and to draw another and higher line above which there would be only one chance in a hundred, and so on for higher and less frequent floods" (Hazen 1930, 2). In 1930, this was a great challenge, one that was only "theoretically possible." Such knowledge would be essential, however, to endeavors such as the successful implementation of flood insurance.

The historical developments out of which Fuller's report emerged cannot be neglected. While the Fuller equations were broadly useful in part because they did not require extensive flood records, they did nonetheless require *some* records. Fifteen years was Fuller's stated minimum record to create a reliable coefficient, and by the early twentieth century, the United States Geological Survey had collected stream flow data over at least fifteen years for numerous waterways. Additionally, interest in floods was increasing in the United States. While the federal government had not yet become involved in flood control and floodplain management nearly to the extent that it would in future decades, it was funding extensive flood control infrastructure – albeit under the guise of navigational improvement – along the Mississippi River, through the Mississippi River Commission (Camillo and Pearcy 2004). Further, regional governmental entities were taking a greater interest in flood control, as evidenced by the major studies commissioned in Pittsburgh and Dayton and discussed previously in this essay.

Though flood probabilities could have many uses, Fuller clearly saw them as a tool to determine the prudent magnitude of physical flood protection structures. His contemporaries, however, recognized that his equations could be useful in other arenas as well. Although Fuller's equation had not been explicitly developed with insurance in mind, his professional colleagues quickly observed its potential importance for that purpose. "Perhaps the best practical idea of the significance of these figures may be obtained by considering them from the standpoint of insurance," Hazen wrote in response to Fuller's presentation. "There is one chance in ten that the 10-year flood will occur in any one year; one chance in one hundred that the 100-year flood will occur; and one chance in 1000 that the 1000-year flood will occur" (Hazen 1914, 630).

Hazen's 1930 book "Flood Flows" did not overturn Fuller's earlier work, but rather refined it. "The methods set forth in Mr. Fuller's paper have been added to and perfected with the lapse of time, but the basic method is still used as the most satisfactory available procedure," Hazen wrote in the introduction to his own volume (Hazen 1930, v). Though Hazen's work included technical refinements to Fuller's methods, perhaps its more interesting contribution is its discussion of the applicability of flood-probability analysis to situations in the real world. This is not to say that Fuller's earlier analysis had been a mere intellectual or academic exercise, but Hazen's book provides insight into the ways that Fuller's work had been utilized in the years since its publication. One important contribution that probability studies added to the body of knowledge concerning floods related to the dominant form of protection employed during the early twentieth century, levees. "Flood prevention work must be wisely directed as otherwise it may prove to be worse than useless," Hazen wrote.

> A levee that holds small floods, but is not high and strong enough to hold a large one, may inspire confidence in the minds of the people through a term of years when the levee functions, and so lead more people to live behind it, and ultimately bring greater disaster (Hazen 1930, 178).

No doubt, this was a statement that could have been made decades or even centuries earlier. The difference, however, was that as probability grew in acceptance as a method to understand flood levels, people could more accurately understand whether the levees they built would be likely to stand up to the larger floods that were possible in their area, because they could gain a better idea of just how great those floods might be.

Through the time of Hazen's 1930 publication of "Flood Flows," work on flood probability had generally been the purview of private enterprise. Though the work of these engineers had sometimes been at the request of municipalities or other governmental entities, government itself had largely been uninvolved in the science of understanding flood frequencies. This would soon change, though. Over the coming years, the federal government would play a growing role in the work on flood probability. Universities also became centers of inquiry into the topic, where before they had not been leading players. The federal government's increased interest in flood probability studies was no doubt related to its increased role in flood protection and floodplain management, a change brought about in large part by the Flood Control Act of 1936. More generally, the policies of Franklin Roosevelt's New Deal had also meant that the federal government was playing an increased role in the creation and dissemination of scientific expertise of various sorts. The growing governmental interest in flood probability was clearly visible in the 1936 publication of *Floods in the United States: Magnitude and Frequency* by the United States Geological Survey (Jarvis 1936).

Though published by the Geological Survey, this massive work was compiled in conjunction with the Mississippi Valley Committee and its successor organization, the Water Planning Committee of the National Resources Board. Its lead author, Clarence Jarvis, was a respected hydrologist in the employ of the USGS. "The need for a more complete and systematic knowledge of floods was impressed upon the Mississippi Valley Committee early in its consideration of public works projects involving river utilization and control," the authors stated in the report's introduction (Jarvis 1936, 10). To address this perception, the report offered an overview of the most important work that had been done on flood frequencies and magnitudes over the past half-century, and also provided flood data for over 200 flood-prone United States rivers, generally at least 20 years' worth of information. The objective of the Jarvis report was not to break new theoretical ground, but to compile the state of the art, both in theory and data, and to make that information broadly available for general reference.

In addition to the release of the Jarvis report, the year 1936 also marked the climax of a dramatic shift in federal flood control policy that would lead the government to take a more active interest in the prediction and understanding of flood magnitudes. Earlier federal flood policy had generally held that benefitting localities must provide a majority of the financial support for flood control projects that received federal dollars. That requirement was lifted for flood control efforts along the Mississippi River in 1928, in recognition of the money already spent by states and localities along that river, and likely also in response to the devastating Mississippi River floods of 1927. As a result of the Flood Control Act of 1936, the rest of the nation was placed on the same standing as the Mississippi River, a piece of legislation that declared flooding to be a threat to the national well-being (Arnold 1988). Because of this assessment of the dangers of floods, the act declared that

> the Federal Government should improve or participate in the improvement of navigable waters or their tributaries, including watersheds thereof, for flood-control purposes if the benefits to whomsoever they may accrue are in excess of the estimated costs, and if the lives and social security of people are otherwise adversely affected (United States 1936).

This legislation clearly suggested the idea of cost-benefit analysis. In terms of flood protection, effective cost-benefit analyses are obviously dependent upon a strong understanding of flood probability. The potential damages caused by a flood of a certain magnitude may be balanced against the likelihood of that flood's occurrence to help determine whether the costs of a given effort at flood control are justified by the benefits they provide (Porter 1995).

The 1930s also marked the beginning of the career of a geographer who would come to play an outsized role in the development of flood plain policy in the United States. Gilbert White began his career working for several New Deal-era federal agencies, including the Mississippi Valley Committee, the Water Resources Committee, and the Bureau of the Budget. White received his education at the University of Chicago, where he studied under the prominent geographer Harlan Barrows (Hinshaw 2006). His reputation would ultimately grow upon the foundation he laid with his 1945 dissertation *Human Adjustment to Floods*, in which he laid out his perspectives on the ways people should use floodplains and adjust to the danger of flooding (White 1945). White had started graduate school in the early 1930s, but his advisor Barrows left his university post to work for the federal government in 1933, and brought his promising student along. White spent most of the 1930s working on flood control projects for the federal government, an experience that helped inform him as he completed his dissertation.

White's dissertation and subsequent work were significant for the emphasis they placed on accommodating floods, in an era when ever-greater flood control and protection structures such as levees and reservoirs had long been the norm. "[F]loods are 'acts of God,' but flood losses are largely acts of man," the young geographer wrote in his dissertation. "Human encroachment upon the flood plains of rivers accounts for the high annual toll of flood losses" (White 1945, 2). On a similar note to the Flood Control Act of 1936, White stressed the importance of flood magnitude and frequency predictions for effective cost-benefit analyses. He was also one of the early proponents of adjustments including flood plain zoning and flood insurance, both of which rely centrally upon strong understandings of flood frequencies and magnitudes.

White's advocacy for flood insurance in the 1940s was not entirely unprecedented, yet neither was he the champion of a product that was already widely available. Private companies had sporadically offered flood insurance to American customers from the late 1890s onward, but none had managed to do so in a financially sustainable manner. Although the federally-backed National Flood Insurance Program was not created until 1968, an earlier effort to institute a federal flood insurance program that took place during the Truman administration is illustrative of the changes occurring in the American political climate by the 1950s, as well as the challenges that remained before a national flood insurance program could be created (Rumsey 2010). Federal involvement in war risk insurance during World War II had provided a model that proponents of flood insurance saw as a valid precedent for their idea, with the federal government underwriting policies offered by private companies. The federal government underwrote these policies because of the broader benefits they offered to society in the form of business confidence – private insurers were unwilling to take the risk themselves – yet these policies also netted the government a tidy profit. Flood insurance proponents hoped for a repeat performance. The United States' self-perceived status as the guardian of the free world and the strongest bulwark against communism also led Truman to couch his support for flood insurance in national security terms that would not have carried the same significance in earlier years.

Ultimately, however, the challenges that Truman's proposal faced, both political and technical, proved to be too formidable. Truman himself hailed from the Kansas City metropolitan area, which was the same region whose floods had inspired the push for a flood insurance program. This surely increased his interest in the rehabilitation of that region, but was likely also on the minds of lawmakers who suspected that the proposal was too regionally driven. Some congressmen feared that a federal system of flood insurance would set a dangerous precedent of government encroachment into the domain of private enterprise, while others saw the proposal as a potential money pit that would do little more than subsidize unwise development in flood-prone regions.

Even if the political will had existed, technical hurdles also presented themselves. The intimate geographical knowledge required to produce insurance ratings was simply not available for many parts of the country in the early 1950s. The difficulties inherent in insuring flood losses demonstrate the unique challenges that high waters posed to those involved in understanding risk, particularly environmental risk. Few other commonly encountered hazards involve such specific geographic variability. One property owner who owns land along a river may be at high risk for suffering flood damages, while a neighbor, 100 feet away but 10 feet higher, may confront very little risk of flood damage. It is hard to imagine 100 feet making nearly as much difference in the level of risk for most other hazards, such as tornadoes, hail, lightning, hurricanes, or fires. Floods present an additional challenge because their risk is not easily quantified. Measures such as elevation or distance from a body of water do not tell the entire story by themselves, but must be combined with flood probability projections, a painstaking process. This theme is clearly evident in the Truman-era discussion of flood insurance. A report issued by the Insurance Executives Association drove the point home especially effectively.

> If flood insurance were to be undertaken without unfair discrimination, it would be necessary to have not only a complete hydrological survey of each river basin and flood area in the country but also a detailed hydrological survey of each 'reach' of each river and, in addition, a detailed survey and appraisal of each property to be insured" (Insurance Executives Association 1952, 9).

The cost of developing such ratings, the report argued, would be "considerable and perhaps in many cases […] disproportionately prohibitive." (Insurance Executives Association 1952, 9-10)

Along with the hurdles it faced, the Truman-led effort also lacked the context of a broader political agenda. While Truman and his administration were not entirely uninterested in environmental issues, the aftermath of World War II occupied the nation's attention over much of his presidency. Little more than a decade later, the scene started to change. Just as Lyndon Johnson's Great Society of the mid-1960s followed the New Deal to form two of the most significant domestic initiatives of the twentieth century, it also produced another wave of important developments in the rationalization of flood risk. The 1960s were a decade of dramatic changes in the emphasis placed on flood probability by the federal government, which went along with a broader slate of environmental initiatives, including the Wilderness Act of 1964 and several pieces of legislation geared toward improving environmental quality. In the introduction to a major 1966 federal report on managing and reducing flood losses, President Lyndon Johnson couched the need for action in the terms of his administration's signature initiative. "[A] Great Society cannot rest on the achievements of the past. It must constantly strive to develop new means to meet the needs of the people," Johnson wrote. "To hold the Nation's toll of flood losses in check and to promote wise use of its valley lands requires new and imaginative action" (United States 1966, iii). The report outlined five basic goals for recommended attention: improvement of basic knowledge on flood hazards, coordination and planning of new developments on flood plains, enhanced technical support for people owning or managing flood plain property, the creation of a national program for flood insurance, and to reexamine federal flood control policy (United States 1966, 1-2). In particular, one objective was that "[a] uniform technique of determining flood frequency should be developed by a panel of the Water Resources Council" (United States 1966, 1).

The Water Resources Council, an eleven-member body that counted several Johnson-administration cabinet members in its number, moved quickly to address this objective, utilizing expertise from governmental arms including the Army Corps of Engineers, the United States Geological Survey, the Soil Conservation Service, the Forest Service, the Weather Bureau, the Bureau of Reclamation, the Bureau of Public Roads, the Federal Power Commission, and the Tennessee Valley Authority (United States 1967, 15). Though the equations for predicting flood magnitude probabilities had been much refined since the days of Fuller, the basic approach endorsed by the Water Resources Council remained the same.

Methodology for flood probability analysis was one question that faced the experts and bureaucrats of the mid-twentieth century. Another issue they had to deal with was making their numbers useful. Would people be most interested in the mean annual flood, which is the highest level of flooding to be expected in the average year? Or, perhaps, the level of flood that could be expected a certain percent of the time? As a result of decisions made around the implementation of the National Flood Insurance Program, the most commonly used standard in the United States, and indeed in many parts of the world, has been the one-percent flood, more commonly referred to as the hundred-year flood. This is the magnitude of flood that is judged to have a one-percent chance of occurring in any one year, and is statistically the average greatest flood to be expected over a 100-year period.

This standard was certainly not a new innovation in the 1960s. As far back as 1934, an Army engineer had published a paper specifically addressing methods of determining the hundred-year flood at any given observation station, and his commentary suggested that he was not the first to make use of this standard

(Pettis 1934). As enacted, the National Flood Insurance Program did not include a specific standard for flood risk guidelines. Rather, the legislation called upon the Department of Housing and Urban Development to come up with a suitable standard, and to achieve this goal, HUD enlisted the aid of the Center for Urban Studies at the University of Chicago. The Center for Urban Studies held a seminar to address the question, and the consensus of the experts present at the seminar was that the hundred-year standard marked a reasonable compromise between prudence and development interests (White et al. 1969).

The institution of the hundred-year floodplain as a legal guideline proved contentious at times. Much of this concern stemmed from two related complaints. One was that the bounds of the floodplain could be inaccurate. The other was that they did not represent reality. John Rousakis, the mayor of Savannah, Georgia, alluded to the first concern in testimony provided to Congress in 1973. Noting that the National Flood Insurance Program was to determine the flood-risk status of communities based upon the 100-year floodplain, the mayor challenged this statistical approach. "This poses no problem if the Secretary approves a contour established on the basis of accurate historical data," the mayor testified. "However, if the contour is established on the basis of unsupported theoretical data, the results can be disastrous" (United States 1973, 50). Rousakis had been notified that the 100-year floodplain in Savannah would be established at somewhere between 14 and 16 feet above sea level, which was several feet higher than any flooding the city had experienced over the past 100 years.

Though formulas to determine the probability of flood magnitudes had been developed over the 50 years prior to the congressional hearing, those on the front lines held strong concerns about how probable flood levels were determined. "I do not know how to identify it – how they arrive at a 100-year flood level," Rousakis stated (United States 1973, 53). His associate, Savannah city manager Arthur Mendonsa, was just as uncertain: "We are told it is a subjective matter, like Alice in Wonderland, it is what someone says it is" (United States 1973, 53). These complaints are demonstrative of the challenges involved in determining the physical area with potential for inundation. Though they may not match up perfectly with predictions derived from formulas or curves, flood flow volumes are nice, cold sets of numbers, easy to manipulate and work with. The greater the flood, the greater the flow volume. Floodplains, however, are much messier. Although the delineation of the 100-year floodplain is approached through a standardized method, Mendonsa had a point when he called it subjective, in that it must depend to some extent on human discernment. Floodplains have varied contours, requiring detailed study. Studies of flood flow magnitudes had given the world the concept of flood recurrences such as the 100-year flood, but truly knowing nature through numbers would be a much taller task.

Some understanding of the challenges involved in translating the 100-year flood into the real world can be gained through an examination of the flood insurance studies produced by the Federal Insurance Administration of the U.S. Department of Housing and Urban Development. Over the mid-to-late 1970s, thousands of these studies were produced, each examining a particular flood-prone city or region in the United States. These studies fulfilled a requirement of the National Flood Insurance Act that communities must undergo flood risk assessments before becoming eligible for participation in the National Flood Insurance Program. Though the studies were produced in the same format (United States, Federal Insurance Administration 1977), they were not produced by a single group or agency. Rather, they were contracted out to federal agencies including the United States Geological Survey, the Army Corps of Engineers, and the National Oceanic and Atmospheric Administration, as well as private firms. Whereas engineers such as Fuller and Hazen had devised and refined methods of calculating flood flow magnitudes and probabilities that were designed to be applied to any stream, each flood insurance study combined methods of probability with painstaking on-the-ground analysis to produce an assessment of flood risk that was deemed sufficient for the purposes of the National Flood Insurance Program.

It would not be accurate to portray the National Flood Insurance Program solely as an agent of improved understanding of flood probabilities. Declarations of flood risk have the potential to be contentions for their effects on property values, and once initial declarations have been made, it is inevitable that strong interests will sometimes oppose newer evaluations that upend established expectations – badly weakening the financial sustainability of the NFIP.[5] However, there can be little doubt that the National Flood Insurance Program's existence has been an important contributing factor in the development of the vast body of knowledge of flood risks in the United States, and by extension, has helped bolster the public awareness of probability and environmental risk. Rather than a simple, unalloyed march of scientific progress, this understanding of floods is the result of specific evolutions in the American sociopolitical climate.

In the early years of the twenty-first century, however, this understanding has been thrown into doubt. Changes in land use have long confounded probabilistic understandings of flood recurrence, and while flood risk assessments are updated from time to time, they often fail to keep pace with the ways people inhabit the land. More recently, and more profoundly, anthropogenic climate change has forced scientists and engineers to examine their assumptions about how the past informs us of the future. Stationarity may now be dead to hydrologists, but the simplicity of the hundred-year floodplain remains seduc-

[5] Steinberg (2000) offers a pointed critique of the National Flood Insurance Program in this vein.

tive.[6] As an idea, it need not disappear, and indeed it remains a powerful way to communicate risk and take the natural world into account – but without methods of understanding flood probability that can take a changing climate into consideration, it will communicate risk inaccurately. As global and regional climates continue to shift, the 'hundred-year' terminology will continue to lose applicability. Flood risks in 2050 may look very different than they did in 1950, or than they will in 2150. A one-percent floodplain is meaningful even in the face of ongoing change. Fuller may have displayed a certain environmental naiveté by assuming that a few years' worth of data from many rivers could substitute for a century's worth from a single stream, but this method did and would have the advantage of capturing a better representation of the present climatic conditions, rather than a long-running average that could include climatically confusing data. At present, it is clear that entrenched financial interests have impeded the success of the National Flood Insurance Program, but even they may be of secondary concern when compared to the challenges of understanding ever-evolving flood risks.

References

Arnold, Joseph. 1988. *The Evolution of the 1936 Flood Control Act*. Fort Belvoir, VA: Office of History, U.S. Army Corps of Engineers.

Camillo, Charles, and Matthew Pearcy. 2004. *Upon Their Shoulders: A History of the Mississippi River Commission from Its Inception through the Advent of the Modern Mississippi River and Tributaries Project.* Vicksburg, MS: Mississippi River Commission.

Daston, Lorraine. 1988. *Classical Probability in the Enlightenment*. Princeton: Princeton University Press.

Flood Commission of Pittsburgh. 1912. *Report of Flood Commission of Pittsburgh, Penna.* Pittsburgh: Murdoch, Kerr, & Co.

Fuller, Weston. 1914a. Flood Flows. *Transactions of the American Society of Civil Engineers* 77: 564-617.

Fuller, Weston. 1914b. Response. *Transactions of the American Society of Civil Engineers* 77: 676-94.

Hazen, Allen. 1914. Response. *Transactions of the American Society of Civil Engineers* 77: 626-32.

Hazen, Allen. 1930. *Flood Flows.* New York: John Wiley & Sons.

Hendricks, David. 2011. *Fundamentals of Water Treatment Unit Processes: Physical, Chemical, and Biological*. Boca Raton, FL: CRC Press.

---

6 The term *stationarity* is used to refer to a process that is stationary, or that occurs randomly within set parameters. Classically, flood recurrence has been understood in this way. Floods were seen as random, but recurring within a known range of possibilities. On the death of stationarity, see Milly et al. (2008).

Hinckley, H. V. 1914. Response. *Transactions of the American Society of Civil Engineers* 77: 622-4.
Hinshaw, Robert. 2006. *Living with Nature's Extremes: The Life of Gilbert Fowler White.* Boulder, CO: Johnson Books.
Höhler, Sabine, and Rafael Ziegler. 2010. Guest introduction to Nature's Accountability: Stocks and Stories. *Science as Culture* 19 (4): 417-30.
Hooper, Michael. 2007 [1965]. Flashback: Melan Arch Bridge Tumbles. *Topeka Capital Journal*, 05/08/2007.
Horton, Robert. 1913. *Frequency of Recurrence of Hudson River Floods*. Washington, DC: U.S. Weather Bureau.
Insurance Executives Association. 1952. *Report on Floods and Flood Damage*. New York: Insurance Executives Association.
Jarvis, Clarence Sylvester. 1936. *Floods in the United States: Magnitude and Frequency*. Washington, DC: U.S. G.P.O (USGS Water Supply Paper 771).
Kennelly, A. E. 1925. *George Chandler Whipple (1866-1924). Proceedings of the American Academy of Arts and Sciences* 60 (14): 654-57.
Kirby, W. H., and M. E. Moss. 1987. Summary of Flood-Frequency Analysis in the United States. *Journal of Hydrology* 96 (1-4): 5-14.
Lübken, Uwe. 2010. Governing Floods and Riots: Insurance, Risk, and Racism in the Postwar United States. *Historical Social Research* 35 (4): 275-88.
Milly, P. C. D., Julio Betancourt, Malin Falkenmark, Robert M. Hirsch, Zbigniew W. Kundzewicz, Dennis P. Lettenmaier, and Ronald J. Stouffer. 2008. Stationarity Is Dead: Whither Water Management? *Science* 319: 573-4.
Oberholzner, Frank. 2011. From an Act of God to an Insurable Risk: The Change in the Perception of Hailstorms and Thunderstorms since the Early Modern Period. *Environment and History* 17: 133-52.
Pettis, C. R. 1934. Flood Probability Formula Modified to Simplify Application. *Engineering News-Record* 112: 804-5.
Porter, Theodore M. 1986. *The Rise of Statistical Thinking 1820-1900*. Princeton: Princeton University Press.
Porter, Theodore M. 1995. *Trust in Numbers: The Pursuit of Objectivity in Science and Public Life*. Princeton: Princeton University Press.
Rafter, George. 1903. *The Relation of Rainfall to Runoff*. Washington, DC: U.S. G. P. O.
Reuss, Martin. 2002. Probability Analysis and the Search for Hydrologic Order in the United States, 1885-1945. *Water Resources Impact* 4 (3): 7-15.
Rumsey, Brian. 2010. *Getting the Ball Rolling: The Truman Attempt at National Flood Insurance.* Unpublished manuscript.
Steinberg, Theodore. 2000. *Acts of God: The Unnatural History of Natural Disaster in America.* New York: Oxford University Press.
Tarr, Joel. 2002. The Metabolism of the Industrial City: The Case of Pittsburgh. *Journal of Urban History* 28 (5): 511-45.
United States. 1936. *An Act Authorizing the Construction of Certain Public Works on Rivers and Harbors for Flood Control, and for Other Purposes. 74th Congress, H. R. 8455*. Public Law, 74-738. Washington, DC: United States Government Printing Office.
United States. 1966. *A Unified National Program for Managing Flood Losses.* Washington, DC: United States Government Printing Office.

United States. 1967. *A Uniform Technique for Determining Flood Flow Frequencies.* Washington, DC: Water Resources Council.

United States. 1973. *Flood Disaster Protection Act of 1973*: *hearings before the Subcommittee on Housing and Urban Affairs of the Committee on Banking, Housing and Urban Affairs, United States Senate, Ninety-third Congress, first session, on S. 1495 and H.R. 8449, to expand the National Flood Insurance Program by substantially increasing limits of coverage and total amount of insurance authorized to be outstanding and by requiring known flood-prone communities to participate in the program, and for other purposes, October 31, 1973*. Washington, DC: United States Government Printing Office.

United States. 1936. *Flood Control Act of 1936*, Pub. L.: 74-738.

United States, Federal Insurance Administration. 1977. *Federal Insurance Administration Flood Map Preparation Standards, May 1973*. Washington, DC: Department of Housing and Urban Development, Federal Insurance Administration.

White, Gilbert. 1945. *Human Adjustment to Floods: A Geographical Approach to the Flood Problem in the United States*. Chicago: University of Chicago.

White, Gilbert, et al. 1969. *Report on Flood Plain Management Guidelines Seminar*. Chicago: Center for Urban Studies, The University of Chicago.

Woodward, Sherman. 1920. *Hydraulics of the Miami Flood Control Project.* Dayton, OH: Miami Conservancy District.